

# NUMERICAL MODELING AND OPERATION OF A HINGED POOL AT OLMSTED LOCKS & DAM

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## Abstract

Upon completion, Olmsted Locks and Dam (L&D) will facilitate navigation on 46 miles of a highly complex system comprised of the lower Ohio River, Tennessee River, and Cumberland River. This reach of the Ohio is greatly influenced by the Mississippi River and lies downstream of these two major tributaries that are subject to rapid flow fluctuations from hydropower releases. To maximize open-river navigation and minimize environmental impacts, a hinged-pool methodology will be used to maintain minimum target elevations upstream at multiple locations. To facilitate operation of the Olmsted wicket and tainter gated dam, an unsteady 1-dimensional model and interface is being developed to assimilate forecasted and real-time input and compute water surface elevations at upstream control points. The program will thus allow the user to perform hypothetical scenarios so that tainter gate changes, wicket-lifting operations, and maintenance procedures can be efficiently planned while maintaining navigation depths both upstream and downstream. This paper will present the planned operation of the hinged pool and aspects of the numerical model currently under development.

## Olmsted Locks and Dam

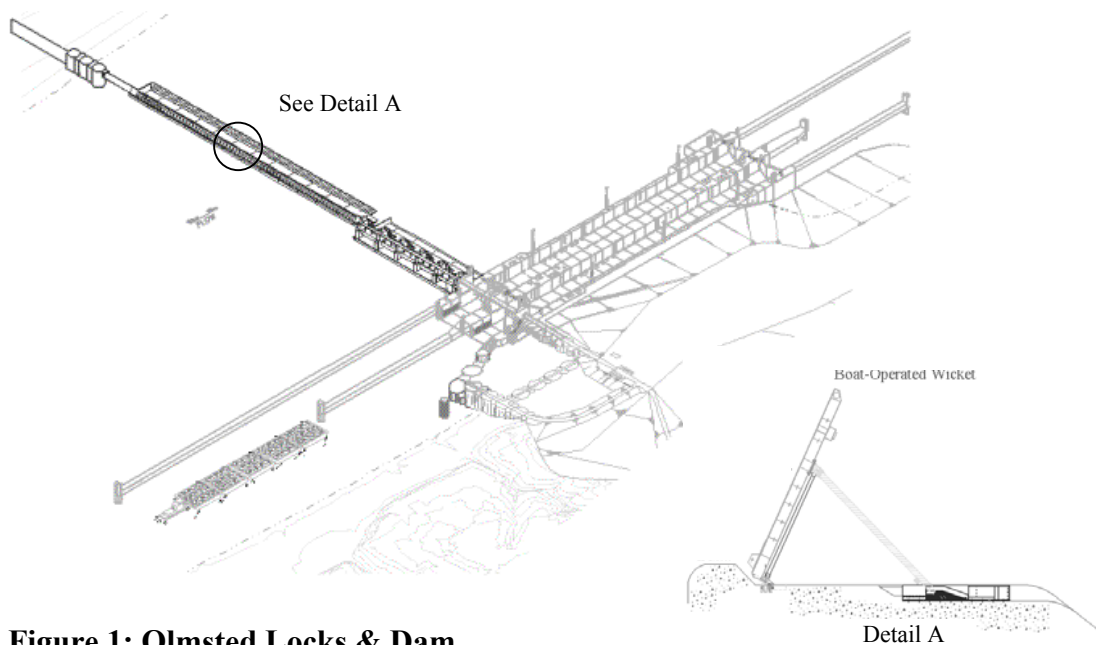
Olmsted L&D (Figure 1) is under construction on the lower Ohio River at Mile 964.4. The completed facility will include twin 110-foot by 1200-foot locks, five (5) tainter gates, and a 1400-foot navigable pass comprised of 10-foot wide, boat-operated wickets. The Olmsted upper pool will be approximately 46 miles long, facilitating navigation to Smithland L&D on the Ohio River, Kentucky Lake on the Tennessee River, and Lake Barkley on the Cumberland River. The Olmsted project will replace aging projects L&D 52 and L&D 53 upstream.

**Hydrology.** The Olmsted project is located in a highly complex reach of the Ohio River, due to the close proximity to the Mississippi River downstream and the

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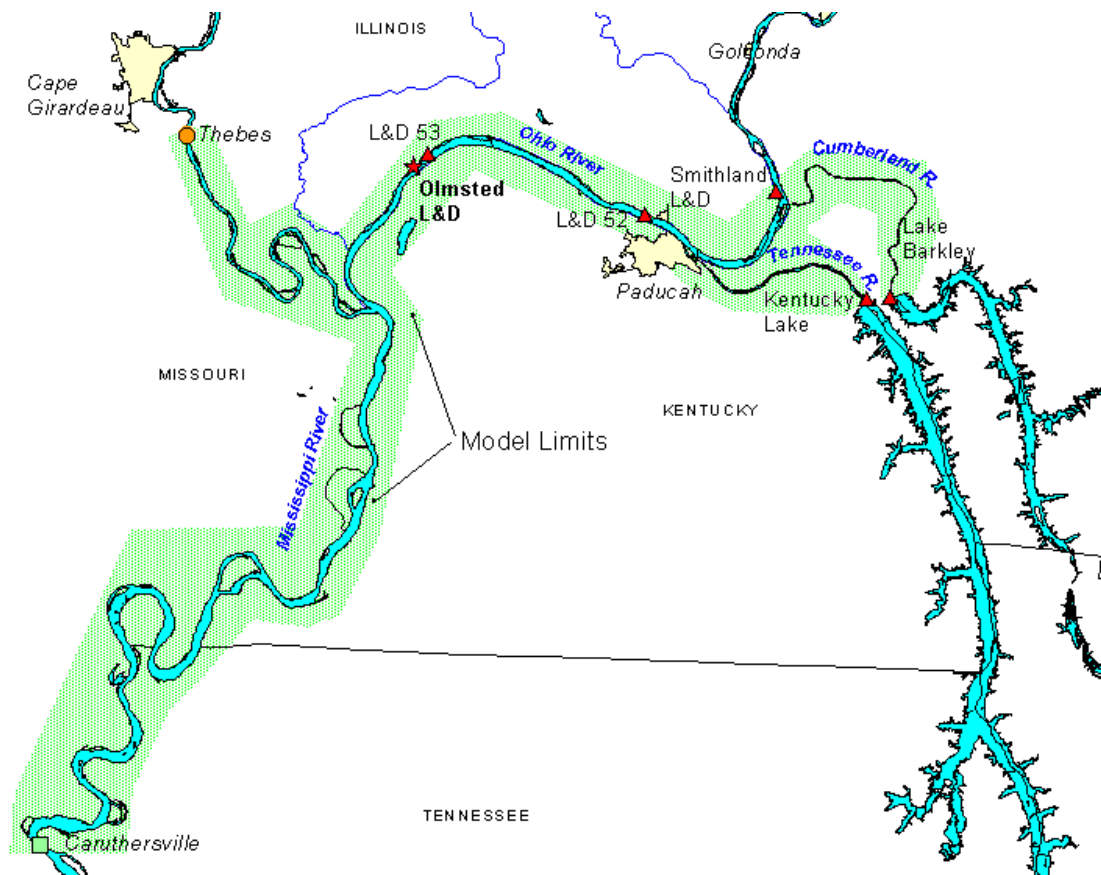


**Figure 1: Olmsted Locks & Dam**

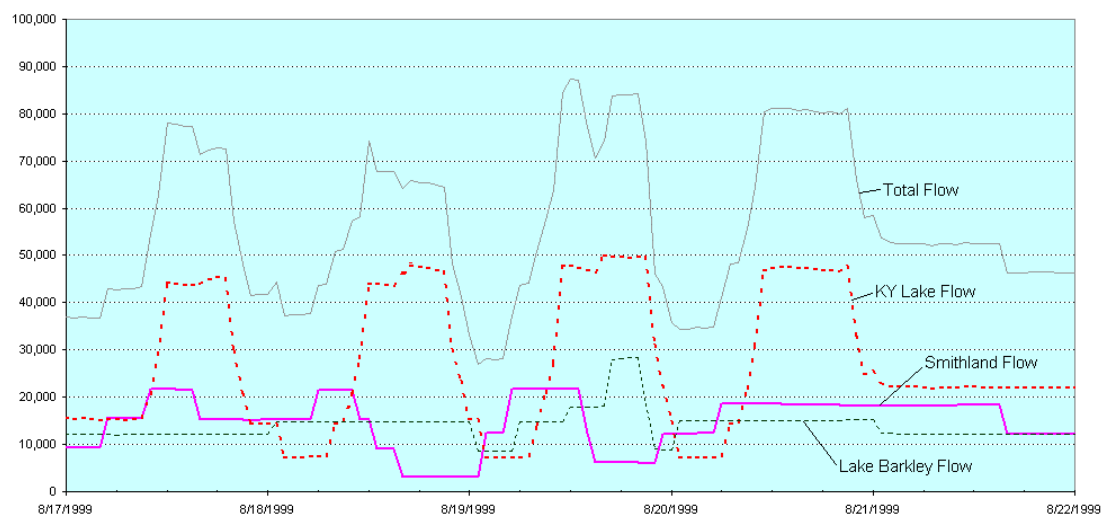
Tennessee River and Cumberland River upstream, as shown in Figure 2. The project is less than 17 miles upstream of the Ohio-Mississippi River confluence. The Tennessee River and Cumberland Rivers join the Ohio River approximately 30 miles and 41.5 miles upstream of the Olmsted site. Kentucky Lake, a Tennessee Valley Authority (TVA) project, and Lake Barkley, a Corps facility, are both subject to peaking/ponding operations to maximize hydropower generation at these sites. Because of a navigation channel connecting Lake Barkley and Kentucky Lake, the hydropower releases from both projects are coordinated to minimize the velocities in the channel. Combined discharge from Lake Barkley and Kentucky Lake can add as much as 75,000 cubic feet per second (cfs) during a peak hydropower release, and can affect this change in flows within a few hours. Figure 3 is an example of the changes in flows due to peak releases and their relative influence during low flows on the Ohio River. During low flow periods, discharges from Lake Barkley and Kentucky Lake can be the dominant component of flow. The drainage area of the entire Ohio River basin to the Olmsted site is over 203,000 square miles. Elevations in this reach have been observed between approximately 278 (record drought) to 337 (flood of record), with fluctuations on the order of 30 to 40 feet occurring regularly during spring flood events.

**Hinged-Pool Operation.** To maximize open-river navigation without compromising navigation conditions, a hinged-pool operation methodology will be used to maintain minimum upstream target elevations of 300 Ohio River Datum (ORD)<sup>3</sup> at Paducah, Kentucky and 302 at the tailwater of Smithland L&D. When flows are adequate to

<sup>3</sup> All elevations in this document reference the Ohio River Datum (ORD) unless specifically stated otherwise.



**Figure 2: Lower Ohio River and Mississippi River (Model Limits)**



**Figure 3: Influence of Hydropower releases during low flows**

maintain a minimum elevation of 295 at Olmsted and the minimum target elevations upstream, all tainter gates will be in the fully raised position and the wicket dam navigable pass will be open to navigation. When it is evident from forecast information that any of the target elevations will not be met, closure of the navigable pass will be planned, with consideration being given to maximize open river navigation and safety of the wicket boat operations. Once the navigable pass is closed, the water surface at the dam will be allowed to fluctuate between elevations 295 and 300. Locking is predicted to occur approximately 40% of the year, based upon analysis of historical flows. Maintaining minimum elevations at the dam during locking will minimize the pool differential, thus minimizing filling and emptying times. The Ohio River downstream of the project is unregulated, therefore the Olmsted project will have limited impact on downstream elevations. When feasible, the tainter gates will be used during low flow periods to dampen and attenuate hydropower peaking flows, and thus minimize rapid changes downstream to the mouth of the Ohio River. Hinged pool operations increases open-river navigation by approximately 30 days per year, and also benefits the environment by maintaining lower pool levels than a level-pool operation.

The influence of the Mississippi River will provide some of the most challenging conditions for maintaining navigable depths in the pool. Periods of high flows on the Mississippi River can combine with low flows on the Ohio, Tennessee, and/or Cumberland Rivers to provide elevations above 295 at Olmsted (adequate for open river navigation) but lower than the target elevations upstream. In such a scenario, the wicket dam will be raised and tainter gates operated in order to provide minimum target elevations at Paducah and Smithland L&D. This scenario typically occurs for a few days annually. Extended durations (up to several weeks) have been observed.

## **Operations Model**

An unsteady 1-dimensional model is being developed to assist with dam operation through assimilation of forecasted and real-time input and computation of water surface elevations at upstream control points. The program will provide minimum recommended dam operations to maintain upstream target elevations and also allow the user to monitor changing river conditions and perform hypothetical scenarios. This will allow the user to efficiently plan tainter gate changes, wicket-lifting operations, and maintenance procedures while maintaining navigation depths both upstream and downstream. Through regular monitoring of real time data, the user can be aware of changing weather situations so that changes to the operation plan can be made.

**Inputs.** The operations model will be dependent on forecasted discharges for Smithland L&D, Barkley Dam, Kentucky Lake Dam, and the Thebes gage on the Mississippi River. The model will access forecasts from the Great Lakes and Ohio River Division (LRD) Water Management office, the Mississippi Valley Division, St.

Louis District (MVS) Water Control office, and TVA. LRD produces a 5-day forecast on a daily basis for all dams and gages on the Ohio River, and will be the source for flows from Smithland L&D. A similar MVS forecast will provide discharges at Thebes. Due to the complexities associated with hydropower generation and water management, TVA and the Nashville District coordinate to produce 24-hour forecasts of releases from Lake Barkley and Kentucky Lake.

In addition to direct releases from regulating structures, an HEC-HMS model is currently in the initial stages of development to account for local inflow to the reach. Due to the size of the Ohio River basin, the additional flow from areas directly contributing to the reach will generally not be a controlling factor; however, in summer and fall low flow periods, this component of total flow could be significant as a result of local storms. A digital elevation model is currently being compiled for the area utilizing 30-meter data from the U.S. Geological Survey (USGS). The HEC-HMS model will be built using HEC-GeoHMS and calibrated to three (3) storms: a historic fall (August - November) event with low flow (elevations) on the Ohio River, a winter (December-February) low flow event, and an event with average Ohio River elevations. The calibrated model output will be added as an additional flow source in the reach.

Data from real-time gages will also be collected and displayed for comparison with forecast information, so that plans can be modified based upon unforeseen weather events. A complexity that the user may have to adjust for is the precipitation assumptions that each forecast uses. Additional capabilities may be investigated that will alert the user of significant real-time discrepancies or automatically adjust the Olmsted operations forecast.

**Model Components.** From the beginning, this model was conceptually made up of several key components: a data acquisition module, a mathematical computational engine, a master control module, and a user interface. Figure 4 shows the planned responsibilities and interaction of model components. Initial plans for the model included development of all components as a specialized, stand-alone package unique to the Olmsted project. The modular design of the model is intended to allow individual modules to be upgraded as changes in technology occur. Further research is required, however it is anticipated that the HEC Corps Water Management System (CWMS) may provide several functions.

**Data Acquisition module.** In addition to collecting, archiving, and formatting input data from the sources described previously, this module must also perform elevation adjustments to correct for differences in referenced vertical datum irregularities. Corps projects on the Ohio River utilize the Ohio River Datum, also known as the Sandy Hook (New Jersey) Datum. The Paducah gage, Kentucky Lake and Lake Barkley Dams gages, and gages on the Mississippi River reference the 1929 National Geodetic Vertical Datum (NGVD). The adjustment between the datums varies significantly by location throughout the model limits. In 1995, the Louisville District Surveys and Mapping Section developed an independent, gravitationally

unwarped datum (identified as the 95G datum) for the Olmsted project using global positioning system (GPS) and National Geodetic Survey benchmarks. This common datum for all key points within the model limits provides a realistic and consistent basis for computations.

**Numerical model.** Much of the development to date has focused on this key component of the model, with the assistance and modeling expertise of ERDC's Coastal Hydraulics Lab. This computational "engine" is FLOWSED, a one-dimensional, unsteady flow model originally developed by Chen (1973), similar to UNET and HEC-RAS, which uses an implicit, finite-difference scheme to solve the equations for conservation of mass and momentum in a channel network (Johnson, 1982). Since 1984, a series of models derived from FLOWSED have been used on a continuous basis to forecast stages along the entire Ohio River. In 1988, an existing model of the lower Ohio River was modified to simulate operation of a hydraulically operated wicket gate dam at Olmsted (Johnson and Weisinger, 1990). This model was subsequently modified to incorporate tainter gates for pool regulation (Chapman, et. al. 1996).

The model is currently configured as a subset of the Ohio River forecast network with a downstream boundary (rating curve) at Caruthersville, Missouri and upstream (inflow) boundaries at Smithland L&D, Barkley Dam, Kentucky Lake Dam, and Thebes, Illinois (see also Figure 2). In its current configuration, the model

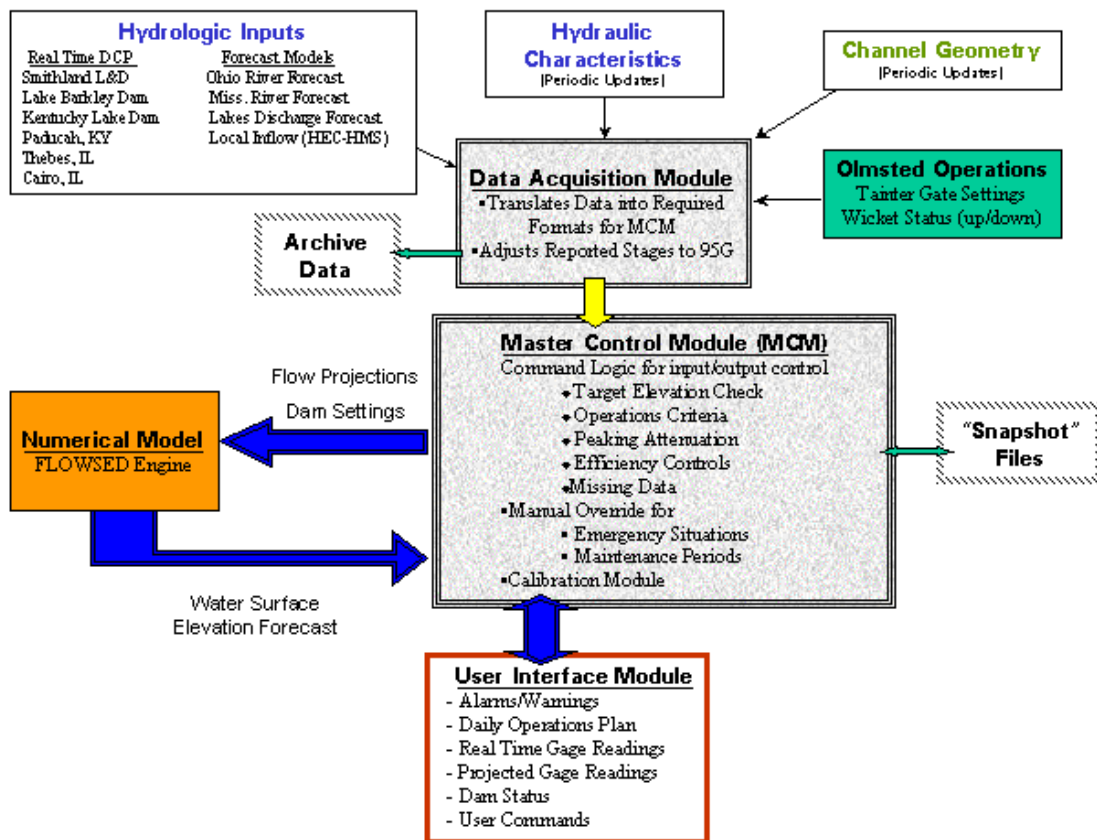


Figure 4. Model components

uses forecast inflows and an "experience" based rating curve to estimate an initial pool hydrograph, a surrogate for gate operations, required to maintain navigation targets at Paducah and the three upstream locks for the next 24 hours. "Experience" has been obtained primarily from physical model and desktop studies and will be updated as on-going and planned physical model studies are completed. If computed hourly stages exceed allowable target ranges, the model attempts to compensate by iteratively adjusting the pool hydrograph and recomputing forecast stages.

***Master Control Module.*** During the early planning of the Olmsted Operations model, a Master Control Module (MCM) was envisioned to regulate and direct the flow of information between the other components of the model. The MCM would contain the control logic for directing the flow of information between components. The MCM responsibilities would include:

*Establishing initial settings.* The MCM would perform initial checks of input data and validate the completeness of the model input. Where boundary condition data is missing, the model will take appropriate action based upon the importance of the information. This action could include automatically seeking alternate gage data and making adjustments accordingly, or prompting the user for alternate actions. The input data may also require adjustment based upon maintenance scheduled or emergency conditions input by the user. Once complete, the MCM would transfer input to the numerical model.

*Evaluating trial output.* After computation of water surface elevations, the MCM will determine if the upstream elevation criteria has been met. If not, the MCM will make adjustments to the dam and time settings, re-create numerical model input, and pass to the numerical model for re-computing. This process will be performed iteratively until upstream criteria are met.

*Peaking Attenuation.* A sub-function of the gate setting algorithm is planned that will allow limited attenuation of peak flows from hydropower releases, so that navigation will not be hampered downstream of Olmsted. This will assist the user in properly planning tainter gate changes without over-compensating, which could result in amplifying the fluctuations, or under-compensating, which could cause higher than necessary pool levels upstream or overtopping of the wicket dam. This will primarily be used during low flows when discharges from Lake Barkley and Kentucky Lake are the dominant components of flow.

***User Interface.*** The user interface will provide the means for entering "what-if" scenario criteria, controlling overall model operations, viewing model input and output, and monitoring changes in the conditions at reporting gages. The interface will operate in the standard Microsoft® Windows® environment. The end user of this program is expected to be the lockmaster at Olmsted L&D or other Operations Division personnel, therefore they will be involved in the final layout and design of the graphical interface.

## **Conclusions**

The complexity of the lower Ohio River hydrology and the proposed hinged-pool

operation of Olmsted L&D will present significant challenges to the Operations staff, as they work to maximize the efficiency of navigation in this heavily traveled reach.

The Olmsted Operations model is being designed to assist with this important task by providing the best possible information regarding forecasted and existing conditions, so that safe and efficient operations can be planned. This will decrease “the learning curve” associated with operating this unique facility.

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